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Fast Response, Blackbody Furnace for Temperatures up to 3000°K

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An inductively heated graphite furnace having a $\frac{3}{8}$-in.-diam source of blackbody radiation for pyrometer calibration is described. The furnace is fabricated from simple, easily demountable parts and may be operated at 1800°K for 6 h with only infrequent attention; temperatures to 3000°K may be obtained for shorter periods. Source temperatures are stable and are rapidly attained. The time constant is approximately $2\frac{1}{2}$ min. Special atmospheres are not required for furnace operation since graphite oxidation is minimized through furnace design. Author

INTRODUCTION

FOR purposes of recalibrating or checking laboratory pyrometers against a calibrated laboratory standard instrument, a small blackbody source was desired. A source unencumbered by windows or other absorbing media was considered necessary to permit direct comparison of monochromatic and two-color instruments. Additional requirements of the furnace were good temperature stability, rapid temperature response, simplicity of fabrication, and ease of assembly. Several small high temperature furnaces have been described in the recent literature.[1–3] Two of these furnaces were operable to temperatures near 3000°K; however, none of them possessed all of the desirable characteristics listed above.

The furnace described herein was developed on the basis of the concepts that have been discussed. Portability and longevity were of secondary consideration.

APPARATUS

The furnace consisted essentially of an inductively heated graphite rod and a zirconium oxide sleeve mounted coaxially from a water-cooled support structure as detailed in Fig. 1. The rod did not extend to the front face of the furnace but only to the rear surface of a zirconia-graphite guard-ring structure as shown in the figure. A photograph of the complete assembly together with a reference tungsten lamp is shown in Fig. 2.

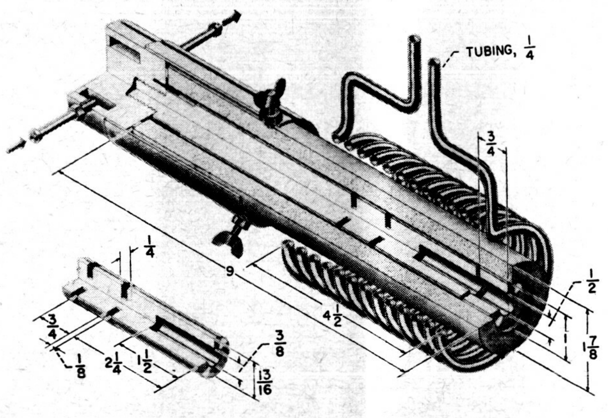

FIG. 1. Dimensional detail of furnace (all dimensions are in inches).

The graphite rod (Fig. 1) was machined from National Carbon Company grade ATJ material. The axis of the rod was made parallel to the grain to ensure maximum strength. The radiating cavity was a simple flat-bottomed hole, $\frac{3}{8}$-in. i.d. and $1\frac{1}{2}$ in. long. Two peripheral grooves ($\frac{1}{8}$ in. wide) were cut as shown to reduce the temperature gradient along the axis.

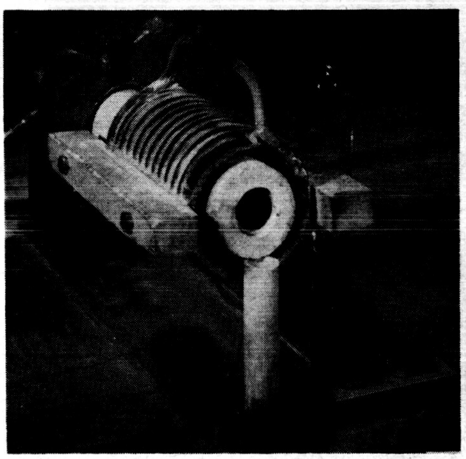

FIG. 2. Furnace assembly and reference tungsten lamp.

The guard-ring assembly consisted of a $\frac{1}{2}$-in.-i.d. graphite cylinder machined to slip fit with a section of 31/32-in.-o.d. zirconium oxide tubing. This assembly served to reduce thermal radiation losses and to shield the graphite rod from oxidation. It could be readily replaced while the furnace was in operation.

The insulating ceramic cylinder was coaxially mounted from the cooled support structure and positioned by the thumbscrew mounts as shown. The cylinder was cast from 8-mesh zirconia castable ceramic obtained from Zirconium Corporation of America. After pouring, the slurry was agitated to eliminate voids; it was subsequently cured at a high temperature. At moderate temperatures, the cylinder

[1] Arthur G. Maki in *Radiation Transfer from Solid Materials*, edited by Henry H. Blau, Jr., and Heinz Fischer (The Macmillan Company, New York, 1962).
[2] G. F. Sitnik, Soviet Astron.—AJ 4, 1013 (1961) [translated from Astron. Zh. **37**, 1076 (1960)].
[3] H. P. Beerman, Ceram. Soc. Bull. **40**, 308 (1961).

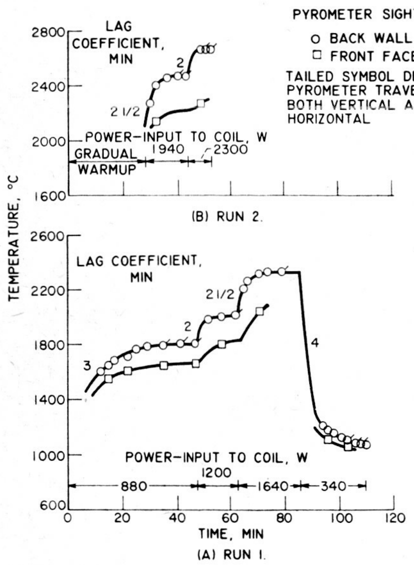

FIG. 3. Furnace performance data.

had sufficient strength to support its own weight when mounted as shown in Fig. 1. To prevent sagging of the cylinder during high temperature runs of long duration, a ceramic tube (Fig. 2) was used as a prop. An asbestos gasket at the rear face of the cylinder sealed the atmosphere from the annulus.

The temperature uniformity of the rear face of the cavity was measured with a monochromatic micro-optical pyrometer. To ensure that the pyrometer was properly focused, it was initially focused on the lamp filament (Fig. 2), which had been aligned in the plane of the rear face of the cavity. When the pyrometer was mounted at distances greater than 16 in. from the furnace, temperature traverses of the rear cavity face could be made to within $\frac{1}{16}$ in. of the edge before vignetting occurred.

RESULTS

The operating characteristics of the furnace are shown in Fig. 3. Although the data plotted are temperature-time variations for only two runs, these data are characteristic of all the data that have been obtained. Temperature data are shown for the front surface of the carbon rod as well as for the rear cavity face. Temperature surveys of the cavity face were only made for the data points represented by the tailed symbols. In all cases there was no discernible variation in temperature at any point on the face.

The power supply for the rf coil of the furnace was a 20-kW, 350-kc generator. Although coil-susceptor design and coupling were not optimized, a coil power of only 2300 W was sufficient for attaining cavity temperatures in excess of 2600°C (Fig. 3).

The time required for a complete pyrometer calibration was relatively short because of the rapid response of the reference surface to a step power input. The time constant (the time required for the reference surface to attain 63% of its final equilibrium temperature following a step change in power) for the furnace ranged from approximately 2 min for a 200°C temperature increase to 3 min for an 1800°C increase. The time constant was approximately the same for both heating and cooling.

Because of the rapid response of the reference surface to changes in power input, the ultimate temperature stability with respect to time is a function of the stability of the rf supply. The output stability of the rf coil was not monitored for the data reported. However, the temperature of the reference face was constant and uniform for periods of 1 h or more providing the guard-ring erosion did not exceed 50 to 60%.

For each of the two sets of data plotted in Fig. 3, a new graphite rod was used. In each case it was estimated that 25% of the useful life of the graphite was expended.

No insulator damage occurred during these runs, which reached a maximum temperature of 2660°C; however, incipient melting of the insulator was noted on a subsequent run when, following a 20-min operation at 2600°C, the cavity temperature was increased to 2730°C for 5 min. A 1-in.-long section of the zirconia casting melted sufficiently to glaze the surface. Continued operation at this temperature probably would have destroyed the casting. The graphite rod used in this run sustained no damage and is shown in Fig. 4(C).

The extent of atmospheric protection afforded the rod by the ceramic can be obtained by a comparison of the rods pictured in Fig. 4. Rod B was operated with an insulator and had a useful blackbody lifetime of about 6 h at 1600°C. Its condition may be compared with that of rod A, which was operated unprotected at 1600°C for a period of 20 min. As previously noted, rod C was operated above 2400°C for 35 min of which 25 min were at temperatures in excess of 2600°C.

Erosion of the graphite rod did not impair the temperature uniformity of the cavity. Nor did erosion cause the temperature of the cavity to drift. The guard ring was gradually destroyed by oxidation and was replaced periodically. Such replacement caused a system temperature unbalance of a few degrees for several minutes before equilibrium was restored. Enclosure of the furnace in a

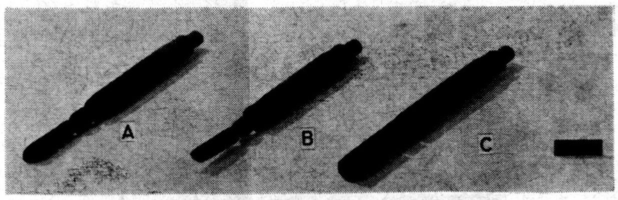

FIG. 4. Graphite rods after testing (A) 20 min at 1600°C without zirconia cylinder, (B) 6 h at 1600°C using complete assembly, and (C) 30 min at temperature above 2400°C using complete assembly.

protective atmosphere would have extended the lifetime and the upper temperature limit of the furnace.[4]

The graphite rod of this furnace had an axial temperature gradient at all points except those near the rear face of the cavity. Hence, the axial position of the induction coil with respect to the graphite rod was critical. An axial displacement of only $\frac{3}{8}$ in. caused temperature variations of as much as 4°C on the cavity face; however, once the coil had been positioned properly, no further adjustments were required either during the course of a run or when a worn graphite rod was replaced.

[4] L. C. F. Blackman. P. H. Duncas, A. W. Moore, and A. R. Ubbelohde, Brit. J. Appl. Phys. **12**, 377 (1961).

The emittance of the cavity was judged to be not less than 0.99. An emittance of 0.995 was obtained from an extrapolation of Buckely's equation[5] for a cylinder length-to-diameter ratio of one and the emissivity value of 0.95 for a sublimated carbon surface. The observed axial temperature gradient would reduce the emittance of the cavity somewhat; however, the decrease would be less than 0.005.

Radiant-intensity measurements obtained with a spectrophotometer having a wavelength resolution of 7 mμ showed no absorption bands throughout the region investigated, 0.4 to 2.6 μ, when the furnace was at 2600°K.

[5] C. S. Williams, Appl. Opt. **50**, 564 (1961).